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Calculations and Analysis of the Radiation Protection of PET/CT Center

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Abstract. Positron Emission Tomography (PET) has been available in number of centers for more than 25 years, but its use was not wide spread until 10 years ago. In Bulgarian PET/CT was installed for the first time in 2009 in Nuclear Medicine Department in University Hospital St. Marina in Varna, Bulgaria. As a physicists the aim for us was to consider and calculate the shielding so that to protect the people and the stuff.

The purpose of this paper is calculating and analysis of the radiation protection and shielding of Nuclear Medicine Center including PET/CT center situated in University Hospital St. Marina in Varna, Bulgaria.

Following the Recommendation of International Commission of Radiation Protection (ICRP) Report # 60, Report # 73, American Association of Physics in Medicine (AAPM) Task Group 108: PET and PET/CT Shielding Requirements, Medical Physics, DIN 6844-3, Installation of Nuclear Medicine; Radiation protection calculation and the Bulgarian regulations in NM, the new Department was made [1,2].

- The design of the Existing Department was renovated following the requirements for PET/CT Center.
- The shielding was calculated for imaging room as well as the uptake room, resting room, the PET control room, places above and under the facility, patient WCs and other surrounding laboratories and stuff cabinets. The radiotracer used for the examinations is fluoro-2-desixyglucose (FDG). FDG is labeled with F-18, whose time of flight is only 109min, but it is positron emitting. The energy of annihilation is 511keV.

The aim was achieved. The Department was opened. It is working now with about 15 patients every day. The dose rates measured with personal TLD's for the last 5 years for the stuff are under 3mSv. As the average dose is around 1mSv, and the doses over 1mSv are only for nurses who injected the FDG.

Keywords: radiation protection, nuclear medicine, FDG, lead shield

Positron Emission Tomography (PET) has been available in number of centers for more than 25 years, but its use was not wide spread until 10 years ago. In Bulgarian PET/CT was installed for the first time in 2009 in Nuclear Medicine Department in University Hospital St. Marina in Varna, Bulgaria.

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Principles in Radiation Protection [6,7]

ALARA, "*As Low As Reasonably Achievable*", is also commonly used is an acronym for an important principle in exposure to radiation and other occupational health risks. The aim is to minimize the risk of radioactive exposure or other hazard while keeping in mind that some exposure may be acceptable in order to further the task at hand.

There are three major ways to reduce radiation exposure to workers or to population:

- Shielding. Use proper barriers to block or reduce ionizing radiation.
- Time. Spend less time in radiation fields.
- Distance. Increase distance between radioactive sources and workers or population

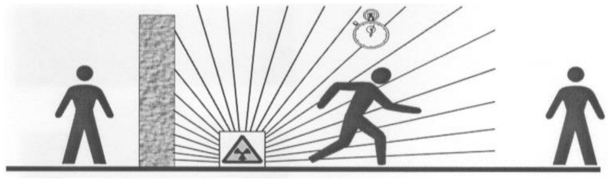

Figure 1. Shield, time, distance.

Radionuclide: FDG

The radiotracer used for the examinations is fluoro-2-desixyglucose (FDG). FDG is labeled with F-18, whose half life is only 109 min, but it is positron emitting. The energy of annihilation is 511 keV.

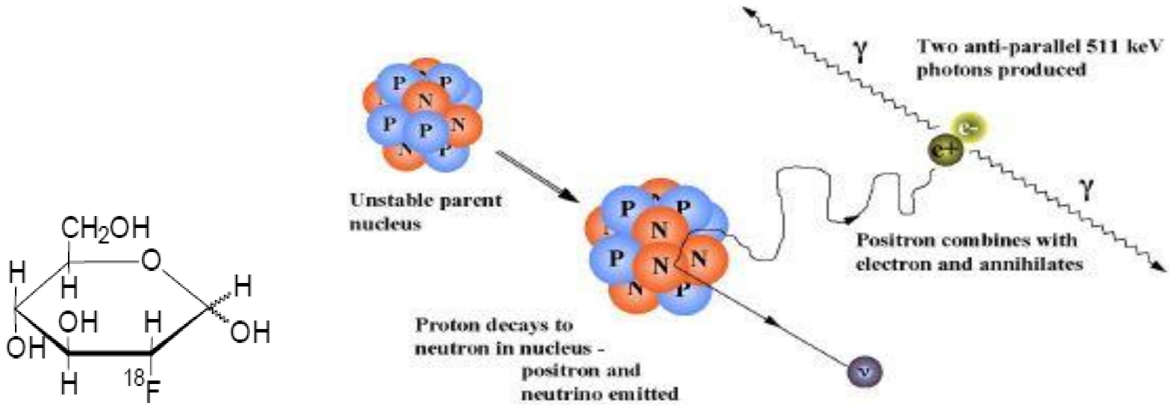

Figure 2. FDG chemical structure.

In body-scanning applications in searching for tumor or metastatic disease, a dose of 18F-FDG in solution (typically 5 to 10 mCi or 200 to 400 MBq) is typically injected rapidly into a saline drip running into a vein, in a patient who has been fasting for at least 6 hours, and who has a suitably low blood sugar. The patient must then wait about an hour for the sugar to distribute and be taken up into organs which use glucose – a time during which physical activity must be kept to a minimum, in order to minimize uptake of the radioactive sugar in muscles (this causes unwanted artifacts when the organs of interest are inside the body). Then, the patient is placed in the PET scanner for a series of one or more scans which may take from 20 to 30 minutes.

The design of the Existing Department was renovated fallowing the requirements for PET/CT Centers.

Method

Calculating the shielding of PET/CT Center using the experience of American Assosiation of Physicists in Medicine (AAPM) Task Group 108 [3,4].

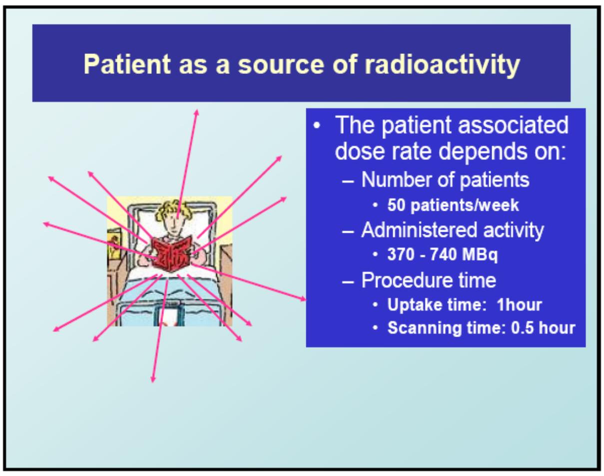

Figure 3. Patient as a sourse of radioactivity.

Needed Information for Calculation

Radionuclide: 18FDG

Administrated activity: 555 MBq

Number of patients per day: 10

Number of patients per week: 50

Uptake time: 60 min

Imaging time: 30 min

Parameters and Equations for Calculating Patient Dose

- A_0 [MBq] — Administrated activity
- t [h] — Time
- t_U [h] — Uptake time
- t_I [h] — Imaging time
- $D(t)$ [μSv] — Absorbed dose
- $\dot{D}(0)$ [μSv/h] — Dose rate
- $T_{1/2}$ [h] — Half life
- R_t — Dose reduction factor

$$R_t = 1.443\frac{T_{1/2}}{t}\left[1 - \exp\left(-0.693\frac{t}{T_{1/2}}\right)\right] \quad (1)$$

for $t = 50$ min, $R_t = 0.86$.

- R_{tU} — Dose reduction factor under the uptake time t_U

$$R_{t_U} = 1.443\frac{T_{1/2}}{t_U}\left[1 - \exp\left(-0.693\frac{t_U}{T_{1/2}}\right)\right] \quad (2)$$

for $t_U = 60$ min, $R_{t_U} = 0.83$.

- R_{t_I} — Dose reduction factor under the imaging time t_I

$$R_{t_U} = 1.443\frac{T_{1/2}}{t_I}\left[1 - \exp\left(-0.693\frac{t_I}{T_{1/2}}\right)\right] \quad (3)$$

for $t = 45$ min, $R_{t_I} = 0.87$.

- N_W — Number of patients per week
- d [m] — Source-shield distance
- F_U — Uptake time decay factor

$$F_U = \exp(-0.693 t_U/T_{1/2}) \quad (4)$$

for $t_U = 60$ min and $T_{1/2} = 109.8$ min, $F_U = 0.68476$.

- T — Occupation factor
- D_{LW} [μSv] — Weekly dose limit

for controlled area $D_{LW} = 400$ μSv;
for uncontrolled area $D_{LW} = 20$ μSv

- B — Transmission factor

$$B = \frac{D_{LW}}{D} \tag{5}$$

- B_U — Transmission factor for uptake room

$$B_U = 10.9 \frac{Pd^2}{TN_w A_0 t_U[\text{h}] R_{t_U}} \tag{6}$$

- B_I — Transmission factor for imaging room

$$B_I = 10.9 \frac{Pd^2}{TN_w A_0 0.85 F_U t_I[\text{h}] R_{t_I}} \tag{7}$$

$$B_I = 12.8 \frac{Pd^2}{TN_w A_0 F_U t_I[\text{h}] R_{t_I}} \tag{8}$$

Uptake Room Calculation

Patients undergoing PET scan need to be kept in a quite resting state prior to imaging to reduce uptake in the skeletal muscles. This uptake time varies from 30 to 90 min but for our clinic it is 60 min. The total dose at a point "d" meter from the patient during the uptake time is:

$$D(t_U) = \frac{0.092[\mu\text{Sv.m}^2/\text{MBq.h}] A_0[\text{MBq}] t_U[\text{h}] R_{t_U}}{d^2[\text{m}^2]} \tag{9}$$

Thus the transmission factor (B) required is:

$$B = \frac{10.9Pd^2}{TN_w A_0 t_U[\text{h}] R_{t_U}}$$

For uncontrolled area

$$B_U = \frac{218d^2[\text{m}^2]}{TN_w A_0[\text{MBq}] t_U[\text{h}] R_{t_U}} \tag{10}$$

For controlled area

$$B_U = \frac{4360d^2[\text{m}^2]}{TN_w A_0[\text{MBq}] t_U[\text{h}] R_{t_U}} \tag{11}$$

B represents the factor that the dose rate has to be reduced by:

B is equal to regulatory dose limit divided by actual (estimated) dose

If $B < 1$ then shielding is required

If $B > 1$ no shielding is necessary

The appropriate thickness of shielding material can be found from the shielding tables or graph as soon as B is determined.

P – weekly dose limit [μSv] different for every country

$P = 400$ μSv for controlled area and $P = 20$ μSv for uncontrolled area

Using the experience for the design of PET/CT Department of other countries and calculation of the shielding the new department was made.

Imaging Room Calculation

Using the same formula, but now we take into account that the administrated activity is decreased during the uptake phase by:

$$D(t_U) = \frac{0.092[\mu\text{Sv.m}^2/\text{MBq.h}] N_w A_0[\text{MBq}] 0.85 F_U t_I[\text{h}] R_{t_I}}{d^2[\text{m}^2]} \tag{12}$$

Thus the transmission factor (B) required is:

$$B = 12.8 \frac{Pd^2}{TN_w A_0 F_U t_I[\text{h}] R_{t_I}}$$

For uncontrolled area

$$B_U = \frac{256d^2[\text{m}^2]}{TN_w A_0[\text{MBq}] F_U t_U[\text{h}] R_{t_U}} \tag{13}$$

For controlled area

$$B_U = \frac{5129d^2[\text{m}^2]}{TN_w A_0[\text{MBq}] F_U t_U[\text{h}] R_{t_U}} \tag{14}$$

Calculation for Rooms Above and Below PET Facility

It is assumed that the patient (source of 511 keV annihilation photons) is situated 1m above the floor. So the dose rate is calculated at 0.5 m above the floor for rooms above the scanner and 1.7 m above the floor for rooms below the scanner room.

The shielding was calculated for imaging room as well as the uptake room, resting room, the PET control room, places above and under the facility, patient WCs and other surrounding laboratories and stuff cabinets.

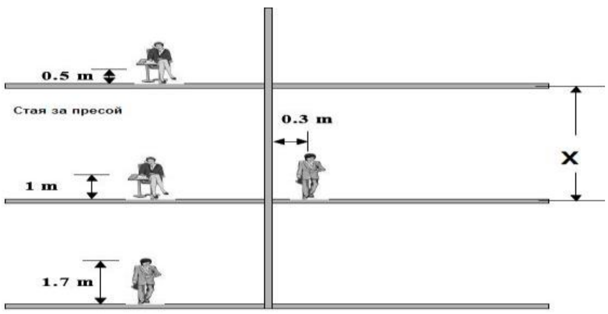

Figure 4. Distance for calculating rooms above and below PET facility.

Calculating the shielding from CT using DIN 6844-3, Installation for Nuclear Medicine; Radiation protection calculation) 1989-2009 [5]

The inner and outer walls was covered with lead sheets of 5, 10 and 15 mm thickness depends on the calculations. The top of the scanner room is covered with 2 mm Pb.

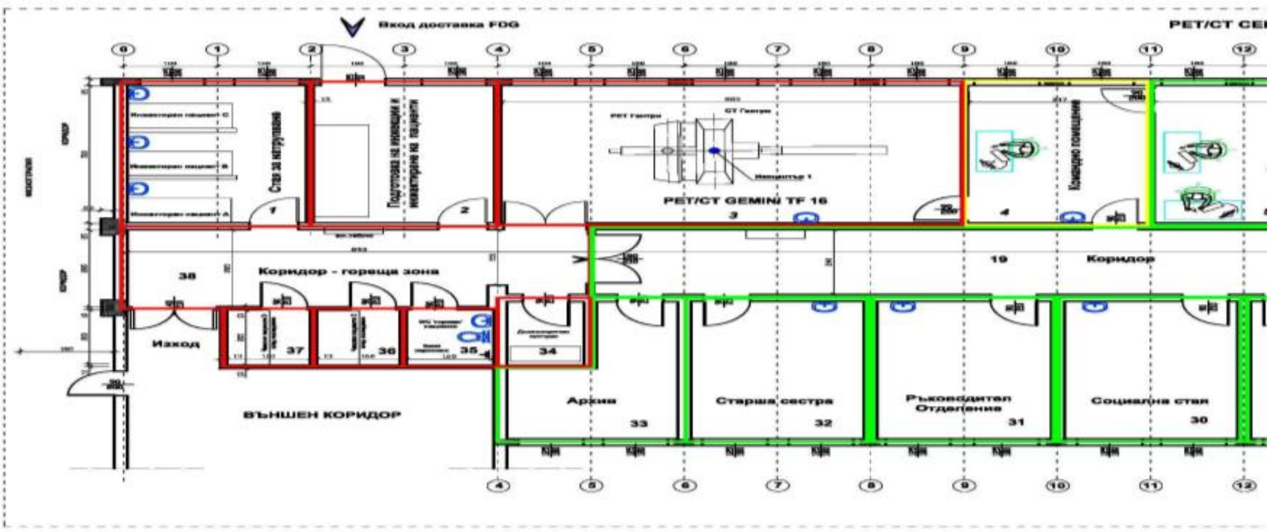

Figure 5. Nuclear Medicine Department.

Results: The aim was achieved. The Department was opened. It is working now with about 10 patients every day. The administrated activity is lower than this using for calculations. It is 0.13 mCi per kilo (about 8–9 mCi average activity per patient). From the beginning FDG came from Debrecen, Hungary by plane every day at noon. Now we have cyclotron installed on site and we produce FDG dose on demand. For every patient we produce personal dose depends on his kilograms.

The work is organized in 2 shifts. The stuff working in this PET/CT Department is:

- 4 physicians
- 4 nurses (injecting patients)
- 3 chemist producing FDG from cyclotron
- 2 technicians doing QC for each FDG dose
- 2 technicians for patient positioning and imaging
- 2 physicist

The dose rates measured with personal TLD's for the last year for the stuff are under 3 mSv. As the doses over 1 mSv are only for nurses who injected the FDG and chemists who produces FDG. The rest personal doses are around (under) 1mSv.

To protect the technicians we have audio and video connection with the patient, and patients are instructed to enter the scanner room and to position their selves alone except immobilized patients.

Future plans: In the future we plan to install injecting system separate or combined with dispensing system so that to decrease the doses of nurses.

Our future plans also include installation of new synthesis module for our cyclotron that will produce not only FDG, but also other short lived PET radionuclides.

References

[1] Recommendation of International Commission on Radiation Protection (ICRP), Report # 60

[2] Recommendation of International Commission on Radiation Protection (ICRP), Report # 73

[3] DIN 6844-3, Installation for Nuclear Medicine; Radiation protection calculation) 1989-2009

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[6] IAEA [1996]. Basic Safety Standard for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115.

[7] Bulgarian regulations (Regulation on basic norms of radiation protection, Regulation for radiation protection during activities with sources of ionizing radiation)